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DMIC

RECENT DEVELOPMENTS

Beryllium

December 30, 1966

PHYSICAL METALLURGY

Brush Beryllium is investigating the effect of high purity on the mechanical behavior of fine-grained beryllium sheet.(1) Primary emphasis in this program is being placed on techniques for achieving a final microstructure and orientation typical of commercial sheet with a minimum of orientation. Powder-metallurgy techniques are being used to maintain a fine grain size. However, one of the major problems involved in these techniques is maintaining a high level of purity while producing a fine-grained power.

Preliminary information on this contract indicates that the fabrication methods being employed are capable of controlling purity in powder-metallurgy beryllium. Oxidation has been minimized by employing argon of sufficient purity during the comminution, screening, die loading, and pressing steps. Grain-growth rate appears to be higher because of the absence of inclusions which tend to retard grain growth. However, pressing characteristics are better in the low-oxide powder which permits the use of lower temperatures for consolidation. Microstructures of these low-oxide pressings and sheets appear extremely clean. As a result, these materials resemble ingot-source beryllium in that the grain boundaries are relatively free of oxide inclusions, but resemble powder-metallurgy materials in that the grain sizes are relatively fine.

London and Stone are studying the mechanical properties of distilled and zone-refined beryllium at Franklin Institute.(2) To overcome difficulties in consolidating the distilled material, they are currently constructing an electron-beam melting unit to aid in this part of their investigation. Impure single-crystal material is being prepared to study the effects of purity. Two such crystals have thus far been tested in microstrain compression. At room temperature, the crystals failed at a compressive stress of 280,700 psi with no detectable plastic strain. Fracture occurred largely on basal and prism planes. Fracture at 208 C (408 F) was on a pyramidal plane.

CORROSION

An investigation of the chemical behavior of beryllium metal exposed to a launch-pad-abort fire environment has been made by Blake at TRW Systems.(3) The purpose of the investigation was to study the toxic beryllium compound particles or smoke that would become airborne during a launch-pad-abort fire. The seven pure combustion-gas species investigated were O_2, N_2, H_2O, NO, CO, and CO_2. At temperatures below the melting point of beryllium, water vapor is predominantly more reactive than the others; above 2000 F, the reactions with oxygen also become important. The other five combustion-gas species are of relatively little importance in terms of reactions that generate significant concentrations of airborne contamination. In an oxygen-rich, hydrogen-oxygen flame, beryllium components heated over 2400 F are likely to ignite and burn in the vapor phase with the release of large amounts of beryllium oxide smoke. This reaction can convert a significant fraction of the beryllium present to smoke. Below 2000 F, relatively little airborne contamination is expected unless a large-scale explosion follows a fire of long duration.

In summary, the degree of interaction between flame environment and beryllium components increases rapidly with increasing beryllium temperature, water vapor, and/or oxygen, and the total pressure of the environment.

FABRICATION

A technique for creep-stretch-wrap hot forming compound-curved skins from thin-gauge beryllium has been developed by Baxter at General Dynamics/Convair.(4) The die used in this operation was formed from Haynes 25, a cobalt alloy, by hammering with a bumping hammer. The die was heated from the bottom by infrared radiation. The beryllium sheet was held along two sides with jaw grippers and stretch wrapped across the die (Figure 1) at a temperature of 1350 F. By this method, a 0.020 x 10 x 24-inch beryllium sheet was successfully formed. When fully developed, this process should allow substantial cost savings in forming compound-curved skins.

Denny and Meyer described techniques for production of fine beryllium wire.(5) The preferred source of material for fabrication stock was vacuum-cast ingots because of the low nonmetallic-inclusion content. Cast ingots are extruded to 3/8-inch-diameter rod and then drawn at 750 to 800 F with 12.5 percent reductions per pass. Speeds up to 200 feet per minute are used.

Major changes in the microstructure are noted as a result of processing the beryllium. The annealed extrusions have an equiaxed grain structure with an average grain size of 48 microns, while conversion of this material to 0.005-inch-diameter

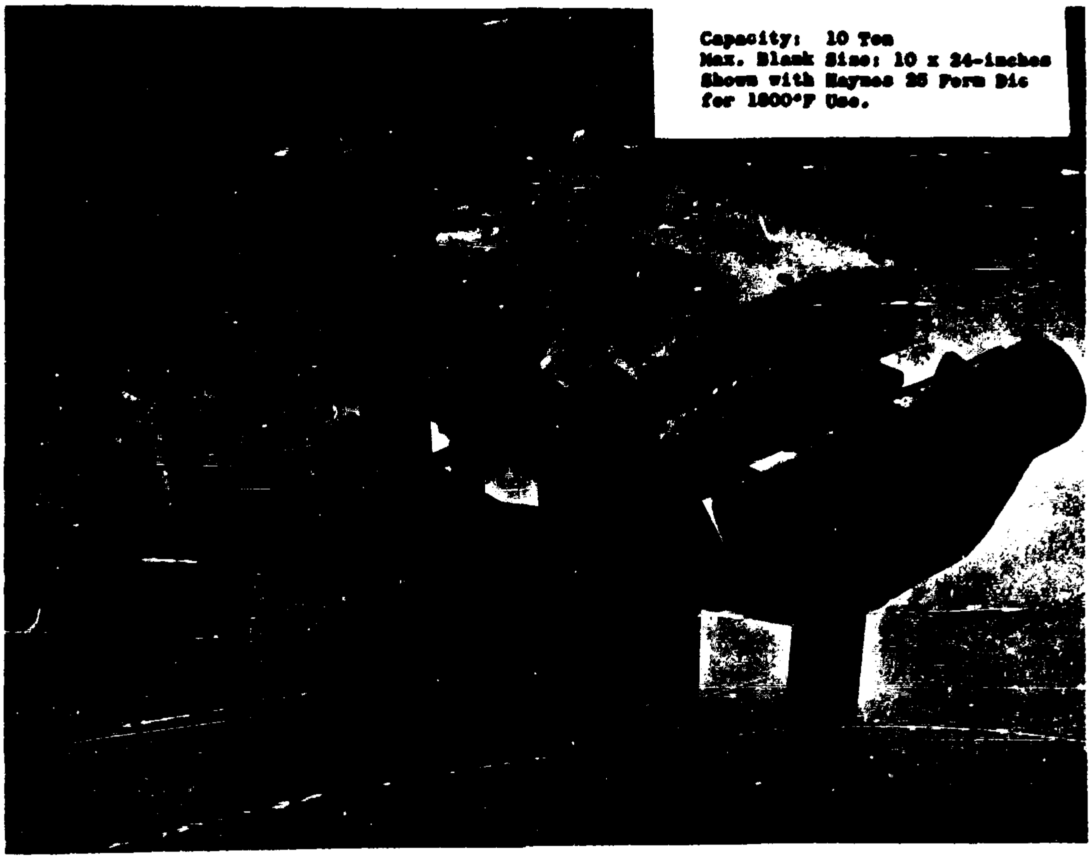

FIGURE 1. COMBINATION CREEP-STRETCH-WRAP MACHINE FOR HOT FORM AND SIZE AGING OF THIN-GAUGE BERYLLIUM(4)

wire yields a grain nominally 2 microns in diameter and 6 microns long. The authors indicated that stress relieving must occur during working since no intermediate anneals are used. Properties of 0.005-inch-diameter wire are listed in Table 1.

TABLE 1. MECHANICAL PROPERTIES OF 0.005-INCH-DIAMETER BERYLLIUM WIRE(5)

Condition	Ultimate Tensile Strength, ksi	Yield Strength 0.2% Offset, ksi	Elongation, percent in 10 in.
As drawn	174.0	137.5	6.3
1/2 Hr, 1000 F	132.9	123.2	6.6
1/2 Hr, 1200 F	115.3	77.7	13.9
1/2 Hr, 1400 F	91.7	49.6	9.0

The forging parameters required for the manufacture of conical beryllium shapes are being developed and evaluated by Hayes and Noel at the Ladish Company.(6) The effects of ten different forging or extruding sequences (Table 2) are being evaluated utilizing different reductions and different combinations of forging operations upon the metallurgical and mechanical properties of the forged, conical beryllium shapes. The Type 4 grade of beryllium is being used because it exhibited superior forgeability in prior testing. The forging billets have been inspected and characterized. This material is currently being processed through the various manufacturing sequences.

The Beryllium Corporation reported on a manufacturing process which was developed to vacuum cast sound beryllium ingots up to 6 inches in diameter and 12 inches long.(7) Empirical equations were developed which showed a relationship between soundness of the ingot and heat-transfer characteristics of the mold. The sound ingots are produced by inducing longitudinal heat transfer with a water-cooled copper plug in the end of the mold. Ingots cast from high-purity melt stock were more susceptible to stress cracking on cooling than those made from regular purity stock.

Beryllium ingot material was successfully upset forged in heavy steel jackets up to 75 percent at temperatures as low as 1375 F. The resultant product showed only slight improvement in mechanical properties. Ingots were also extruded into mill shapes in the 1650 to 1950 F temperature range. Reductions of 12:1 to 25:1 resulted in sound extrusions with improved properties and very little preferred orientation.

TABLE 2. PROCESSING SEQUENCES USED TO STUDY PARAMETERS REQUIRED IN THE MANUFACTURE OF CONICAL BERYLLIUM SHAPES[6]

Sequence	Operation	Reduction
1	Back extrude	3.4:1
	Form	
2	Back extrude	2.5:1
	Form	
3	Upset	80 percent (5:1)
	Back extrude	3.4:1
	Form	
4	Upset	80 percent (5:1)
	Back extrude	2.5:1
	Form	
5	Upset	75 percent (4:1)
	Back extrude	3.4:1
	Form	
6	Forward extrude	4:1
	Upset	60 percent
	Back extrude	3.4:1
	Form	
7	Forward extrude	4:1
	Upset	60 percent
	Back extrude	2.5:1
	Form	
8	Forward extrude	4:1
	Upset	75 percent
	Back extrude	3.4:1
	Form	
9	Forward extrude	3:1
	Upset	60 percent
	Back extrude	3.4:1
	Form	
10	Forward extrude	3:1
	Upset	75 percent
	Back extrude	3.4:1
	Form	

Extrusions, forgings, and as-cast ingots were converted into sheet by rolling in the temperature ranges of 1100 to 1200 F and 1450 to 1650 F. Special solutionizing and precipitation treatments were used prior to fabrication to produce consistently sound sheet in the low-temperature range. Extruded slabs were the preferred starting stock since they could be consistently rolled in both temperature ranges. Residual cold work in sheet rolled in the lower temperature range gave higher tensile properties and lower elongations. On the other hand, sheet fabricated in the higher temperature range showed greater formability.

A pamphlet summarizing the available machining data for beryllium metal has been compiled by Snider and Kahles.[8] This pamphlet gives machining-data charts with explicit specification for each machining process.

NASA has issued a series of technical memoranda concerning the fabrication of beryllium. The first volume is a reprinting of a report written for the Redstone Scientific Information Center by Gerds and Boulger at Battelle.[9] This report, which has already been reviewed, covers a survey of technology in beryllium fabrication from 1960 to 1964. Volume II covers forming techniques for beryllium alloys.[10] The problem of forming structural components from sheet products is detailed. Time-temperature relationships are established for the forming of straight bends, compound curved channels, joggles, and hemispherical segments. Examples showing flow of material and resultant dimensional changes are measured. This report shows the feasibility of using extreme forming operations on cross-rolled beryllium sheet.

Metal-removal techniques are the subject for Volume III of this series.[11] A review of the proven production techniques for drilling, routing, and abrasive wheel cutting of both sheet and plate thicknesses of beryllium is given. Also, production techniques for precision machining of hot-pressed block and extruded rod are reviewed. An investigation of chemical-milling rates versus solution strengths is described. Electrical-discharge machining power and frequency parameters and electrode materials are correlated with the resulting metal-removal rates, surface finishes, and machining times. Metallographic techniques were used for comparison and failure analysis.

Volume IV of this series covers surface-treatment techniques used in the fabrication of beryllium structures.[12] One section of this report covers removal of surface contaminants incurred during normal shop handling. This would include removal of fingerprints, lubricants, dust, etc., resulting from normal working of the structures. Another part of this report discusses the chemical removal of surface oxides for adhesive bonding and plating. In the case of bonding, the cleaning agent must be compatible with the bonding process and must not contain compounds which would inhibit proper curving of the bonding material. Etching is employed to clean the surface prior to plating. Then an activating strike is normally employed prior to final plating. Procedures for zinc, copper, and nickel plating are given. Also described are procedures followed to prevent surface damage during shop operation.

The effects of thermal treatments on the properties and dimensional stability of formed beryllium sheet are reported in Volume V.[13] It was found that relief of residual stresses could be more readily accomplished at 1025 F rather than the more commonly used 1350 F. Rapid cooling after thermal treatment was not a recommended production process since it has a deleterious effect on both the properties and contour of formed sheet. Annealing at 1150 F for 8 hours results in more consistent effects than do similar treatments at 1350 F.

Joining techniques was the topic for Volume VI in the series.[14] This document covers primarily mechanical fastening and adhesive bonding. It was concluded that high-strength mechanical fasteners can be used for fabrication of beryllium structures. Adhesives are not necessary in conjunction with mechanically fastened joints. However, satisfactory adhesive joining of beryllium was accomplished on a laboratory scale. In both cases it was demonstrated that these techniques could be used to produce sound joints. Brazing is the most advanced technique of the two. However, the authors recommended that both techniques be developed further since there were few established production techniques for these procedures.

STRUCTURES

Oken and Dilks have preformed a structural evaluation of beryllium solar panel spars at the

Boeing Company (Figure 2).(15) Beryllium cross-rolled sheet with a 2 percent maximum BeO content was used in this program. It was initially characterized in the bare condition after being wetted with Al-12Si braze alloy to verify the material specifications. To evaluate the beryllium under operational loading conditions, four solar panel spars were fabricated and tested. Three were brazed and one was riveted. Present cross-rolled beryllium-sheet flatness specifications of ±2 percent were determined to be inadequate and the sheet, therefore, had to be flattened before use. Fabrication was very successful inasmuch as all established design and process criteria were followed. The four spars were tested to failure, which occurred at stress levels from 37,600 to 41,000 psi.

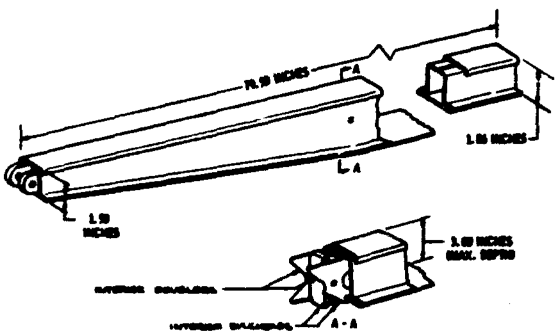

FIGURE 2. BERYLLIUM SOLAR SPAR USED IN STRUCTURAL EVALUATIONS AT BOEING(15)

Hauser and coworkers at Battelle have reported on the electron-beam welding of beryllium.(16) This report covers half of a 2-year program on the subject. Procedures have been investigated for welding 0.020-, 1/16-, 1/8-, and 1/4-inch thick sheet. The factors which were examined for their effect on weld quality were beam voltage, current, diameter, travel speed, preheat temperature, surface preparation, mechanical restraint during welding, and material composition. In the thicker sheets, undercutting and surface roughness of the welds were major problems in developing satisfactory welding procedures. Lower welding speeds and power densities, multiple-pass welds, and the addition of filler metal alleviated the undercutting and roughness problems.

BeO films, the thickness of which increased oxide content, were found to form on the welds. Undercutting, roughness, and porosity in the welds tended to increase with the BeO content of the base metal. For a given set of conditions, the quality of welds in the low-oxide (0.69 percent BeO) sheet was significantly better than that in the high-oxide (1.93 percent BeO) material.

Preheating was necessary to prevent cracking when restraint was used in butt-welded sheets. It was necessary to use higher temperatures as restraint was increased. Distortion during welding was determined to be the same as in welding aluminum or stainless steel. Transverse shrinkage and longitudinal bowing were the primary means of distortion that were measured. Multiple-pass welds at lower power densities produced more distortion than single-pass welds at higher densities.

Bend tests on welded sheet indicated that the ductile-brittle transition temperature was about twice that for the base metal (1200 F versus 535 F). Limited tension testing on welded sheet gave joint efficiencies of 55 to 75 percent in the range of -40 to 800 F. Tests were made in 1/16- to 1/8-inch-thick sheet. Loss in properties was attributed to the relatively large grain size of the weld.

NEW CONTRACTS

The previous Beryllium Review (September 23, 1966) referenced a Metalworking News item (May 9, 1966) which incorrectly stated that Case Institute of Technology will be determining the feasibility of producing fine beryllium wire by hydrostatic extrusion and drawing. Instead, this work is being done by Battelle Memorial Institute on an Air Force contract as part of the Battelle hydrostatic extrusion program.

Beryllium Corporation is investigating techniques for producing solid-solution-strengthened beryllium-alloy sheet under a Navy Air Systems Command Contract.(17) Ingots of higher purity beryllium are to be alloyed with copper and fabricated into fine-grained sheet. The goals are to produce sheet with low anisotropy, fine grain size, and the bending characteristics of ingot sheet combined with the strength of commercial sheet. Preliminary results have indicated that the copper additions give an alloy with good casting characteristics. The extrusion constant of the ingots increased with increasing copper content. Surface roughness in the extruded beryllium-alloy slabs could be related to grain-size variation in the casting.

NASA-Marshall Space Flight Center has recently awarded a contract to Harvey Aluminum Company to investigate roll bonding of stiffened-rib sandwich structures.(18) Both beryllium and beryllium-titanium structures will be investigated. The first phase of the program will be concerned with design, fabrication, and testing of samples representing the joints required in the final assembly. All the important process variables will be optimized by using these test samples after which full-scale sandwich structures will be fabricated using the parameters developed during the first phase.

REFERENCES

(1) Preliminary information reported by Brush Beryllium Company, Cleveland, O., under an Air Force contract.

(2) Preliminary information reported by Franklin Institute Research Laboratories, Philadelphia, Pa., under an Air Force contract.

(3) Blake, V. E., "An Experimental Investigation of the Behavior of Beryllium Metal in Simulated Launch Pad Abort Environments", Final Report SC-DC-65-1637, TRW, Inc., TRW Systems Group, Redondo Beach, Calif., Sandia Corporation Contract 82-6211 (July, 1965). DMIC No. 64928.

(4) Baxter, G. I., "Forming Thin Gauge, Low Ductility Metals Magnesium, Titanium, Beryllium", Report GDC-ERR-AN-873, General Dynamics/Convair, San Diego, Calif. (December, 1965). DMIC No. 65244.

(5) Denny, J. P., and Meyer, G. E., "Beryllium Ingot Wire", Wire and Wire Products, 41 (10), 1640-41, 1712-13 (October, 1966) DMIC No. 66278.

(6) Preliminary information reported by Ladish Company, Cudany, Wis., under an Air Force contract.

(7) Meyer, G. E., "Casting and Hot Working of Sound Large Diameter Beryllium Ingots", Final Report AFML-TR-65-361, The Beryllium Corporation, Reading, Pa., Contract AF 33(657)-10943 (September, 1965) DMIC No. 62806.

(8) Snider, R. E., and Kahles, J. F., "Machining Data for Beryllium Metal", Report AFMDC 66-3, Metcut Research Associates, Inc., Air Force Machinability Data Center, Cincinnati, O., Contract AF (615)-5262 (June, 1966) DMIC No. 65389.

(9) Williams, R. F., and Ingels, S. E., "The Fabrication of Beryllium-Volume I: A Survey of Current Technology", Technical Memorandum X-53453, NASA-George C. Marshall Space Flight Center, Huntsville, Ala., Contracts NAS 8-11798 and DA-01-021-AMC-203(Z) (July, 1966) DMIC No. 65994.

(10) Williams, R. F., and Ingels, S. E., "The Fabrication of Beryllium-Volume II: Forming Techniques for Beryllium Alloys", Technical Memorandum X-53453, NASA-George C. Marshall Space Flight Center, Huntsville, Ala., Contract NAS 9-11798 (July, 1966) DMIC No. 65987.

(11) Williams, R. F., and Ingels, S. E., "The Fabrication of Beryllium-Volume III: Metal Removal Techniques", Technical Memorandum X-53453, NASA-George C. Marshall Space Flight Center, Huntsville, Ala., Contract NAS 8-11798 (August, 1966) DMIC No. 65988.

(12) Williams, R. F., and Ingels, S. E., "The Fabrication of Beryllium-Volume IV: Surface Treatments for Beryllium Alloys", Technical Memorandum X-53453, NASA-George C. Marshall Space Flight Center, Huntsville, Ala., Contract NAS 8-11798 (July, 1966) DMIC No. 65998.

(13) Williams, R. F., and Ingels, S. E., "The Fabrication of Beryllium-Volume V: Thermal Treatments for Beryllium Alloys", Technical Memorandum X-53453, NASA-George C. Marshall Space Flight Center, Huntsville, Ala., Contract NAS 8-11798 (July, 1966) DMIC No. 65992.

(14) Williams, R. F., and Ingels, S. E., "The Fabrication of Beryllium-Volume VI: Joining Techniques for Beryllium Alloys", Technical Memorandum X-53453, NASA-George C. Marshall Space Flight Center, Huntsville, Ala., Contract NAS 8-11798 (July, 1966) DMIC No. 65993.

(15) Oken, S., and Dilks, B. H., "Structural Evaluation of Beryllium Solar Panel Spars", Report AFFDL-TR-65-45, The Boeing Company, Seattle, Wash., Contract AF 33(657)-11736 (August, 1966) DMIC No. 65708.

(16) Hauser, D., Mishler, H. W., and Monroe, R. E., "Electron-Beam Welding of Beryllium", Report AFML-TR-66-215, Battelle Memorial Institute, Columbus, O., Contract AF 33(615)-2671 (July, 1966) DMIC No. 65499.

(17) Preliminary information reported by Beryllium Corporation, Reading, Pa., under a Navy contract.

(18) Preliminary information reported by Harvey Aluminum Company, Torrance, Calif., under a NASA contract.

DMIC Reviews of Recent Developments present brief summaries of information which has become available to DMIC in the preceding period (usually 3 months), in each of several categories. DMIC does not intend that these reviews be made a part of the permanent technical literature. Copies of referenced reports are not available from DMIC; most can be obtained from the Defense Documentation Center, Cameron Station, Alexandria, Virginia 22314.

R. W. Endebrock, Editor